

REMARKS

By the present amendment, claims 3-6 and 16-17 are pending in the application. Claims 16 and 17 are independent claims.

Claim Amendments

Independent claims 16 and 17 have been amended by the present amendment to clearly point out that "the metal balls are only adhesive bonded to the electrodes with a flux without reflowing".

The last paragraph of prior independent claims 16 and 17, referring to flip chip bonding, has been deleted to emphasize that the metal balls are only adhesive bonded to the electrodes with a flux and have not been reflowed. Claims 16 and 17 claim a device. Reflowing of the metal balls would only take place at a later time in a manufacturing process.

Independent claims 16 and 17 have been amended by the present amendment to clearly distinguish the present invention over the prior art.

Independent claims 16 and 17 have also been amended by the present amendment in response to the comments in the Advisory Action mailed May 20, 2002. For example, the Advisory Action states at page 2, Continuation of 10, at lines 5-6: "The claims do not recite balls that have not been subjected to a reflowing process". It is submitted that amended claims 16 and 17 of the present amendment clearly recite balls that have not been subjected to a reflowing process.

It is submitted that amended independent claims 16 and 17 of the present amendment are patentable over the prior art of record.

Claim Objections

Claim 16 was objected to in the Office Action mailed August 14, 2002 because the symbol "-" between semi and conductor needs to be deleted. By the present amendment, claim 16 has been amended to delete the symbol "-" between semi and conductor.

In view of the present amendment, it is respectfully requested that the objection to the claims be withdrawn.

§103

Claims 3-6, 16 and 17 were rejected in the Office Action mailed August 14, 2002 under 35 U.S.C. §103(a) as being unpatentable over U.S. Patent No. 4,940,181 to Juskey, Jr., U.S. Patent No. 5,470,787 to Greer; U.S. Patent No. 6,254,923 to Boyd et al. in view of the Periodic Table of the Elements.

These rejections, as applied to the amended claims, are respectfully traversed.

The Present Invention

The invention of the present application relates to the art of semiconductor devices which will at a later time be flip chip bonded to a substrate.

More specifically, the present invention, as defined in amended independent claims 16 and 17, is specifically directed to electrodes of a semiconductor device

wherein metal balls are only adhesive bonded to the electrodes with a flux without reflowing.

At a later time the claimed semiconductor device comprising electrodes with metal balls only adhesive bonded to the electrodes without reflowing of the metal balls is mounted on a substrate by flip chip bonding.

Discussion

A general process for flip chip bonding a semiconductor device to a substrate is illustrated in Figs. 1A to 1H, attached hereto.

Attached Fig. 1A shows, at the left side, a silicon wafer in which a number of semiconductor devices are fabricated together, and, at the right side, a section of an electrode pad of aluminum of a fabricated semiconductor device formed on the wafer with passivation.

On the electrodes of the devices, UBMs (Under Bump Metals, which are referred to as laminated layers in the specification of the present application) of, for example, Ni and Au are formed (Fig. 1B). Solder balls are then formed on the UBMs.

Traditionally, the formation of bumps is carried out by a printing process, in which solder paste is applied on to each of the UBMs, and is then fused for reflowing at an elevated temperature to be bonded to the electrode through the UBM, during which the solder paste is formed into a dome-like shape by the action of surface tension. Alternatively, solder material is plated on the UBMs using a photo resist mask, the solder is then raised to an elevated temperature to

be fused and formed into a dome-like shape. See Figs. 1C and 1D, attached hereto.

The wafer is then diced to provide individual chips (semiconductor devices), as shown in attached Fig. 1E. The chip is connected to a mounting substrate by bonding (flip chip bonding) the bumps of the chip to the electrodes of the substrate. For the bonding, flux is applied to the electrodes of the substrate so that the bumps are connected to the electrodes of the substrate through the intervening flux. The assembly of the chip and the substrate is then heated to an elevated temperature to fuse the solder bumps and accomplish the bonding of the chip to the substrate. See Fig. 1F, attached hereto.

If the heights of the bumps vary widely at this stage, the connection between the bumps and the electrodes of the substrate is frequently bad. Therefore, it is important that the bumps formed at the stage depicted in Fig. 1D have uniform heights or volumes. In other words, the variation in the heights or volumes of the bumps is one of main causes of fault of an expensive semiconductor device (see the right side of attached Figure 1H).

Appendix I, attached hereto, illustrates the three processes for the formation of bumps.

The present application provides a semiconductor device having solder balls of its electrodes, as shown in the right column of attached Fig. 1C, which are subsequently made into bumps having a uniformity of heights after reflowing (Fig. 1D). This is made feasible by the use of the solder

balls, the balls being uniform in their heights (or diameters), which is a result of the present invention. See attached Appendix II.

As shown in the right column of attached Fig. 1C, in the invention of the present application, a certain amount of flux is applied to each of the UBMs provided on the electrodes of a semiconductor device, and a solder ball is fixed (adhesive bonded) to the electrode using only adhesion of the flux. Accordingly, the semiconductor device of the present invention comprises the solder balls provided on its electrode, with the balls being fixed to the electrode only by the adhesion of the flux, and have not yet been reflowed.

At a later time, the solder balls may be reflowed at an elevated temperature and formed into bumps, which are uniform in height because of the use of the solder balls which are uniform in diameter. As such, the semiconductor device of the present invention does not have bumps but does have solder balls.

The semiconductor device of the present application is at a later time mounted on a substrate. In the case where balls are mounted on a chip previously diced from a wafer, the formation of the bumps and the mounting of the chip to a substrate can be performed at one reflowing, as described below.

The semiconductor device of the present application can be isolated, as a chip, from others by dicing a wafer, and solder balls can be then fixed to the UBMs of the electrodes of the device (chip). Using this device (chip) of the present application, the electrical connection between

the solder balls (bumps) and the electrodes of the device and the electrical connection between the balls and the electrodes of a substrate can be simultaneously achieved. Thus, the device of the present invention allows flip chip bonding of the device to a substrate by one heating (reflowing) process. Furthermore, the device of the present invention provides the bumps certainly connecting the electrodes of the device to the electrodes of the substrate. In addition, with the invention of the present application, solder balls can be selectively provided only on the devices (chips) of good quality. These benefits cannot be obtained using conventional techniques for the formation of bumps (evaporation, plating, and screen printing). (See attached Appendix II). This is because the conventional methods need to subject a wafer to processes using a mask and a resist material, and the formation of bumps for a diced individual chip is very inefficient.

For the purpose of reference, the attached article, Micro-Ball Wafer Bumping for Flip Chip Interconnection, demonstrates the superiority of the unreflowed solder ball to bumps formed by a conventional process, such as evaporation, plating, or printing. In particular, Fig. 12b compares height variation of bumps formed from solder balls with bumps formed from printed solder paste. (It should be noted that although Fig. 12b contains two graphs, the upper graph was designated as Fig. 12a when the authors, including the inventors of the application, sent the draft to IEEE, as can be seen in attached Appendix III).

Patentability

The invention of the present application is set forth in amended independent claims 16 and 17, which the Office Action has rejected based on Juskey, Jr. and Greer.

Juskey, Jr., cited by the Office Action, relates to the bonding of the chip (or wafer) to a substrate, which corresponds to the step illustrated in attached Fig. 1F. The chip is provided with bumps which have already been connected to the electrodes of the chip through a reflowing process. In contrast, the device (chip) of the present invention is provided with solder balls only fixed (adhesive bonded) to its electrodes through flux, and does not have bumps resulting from the reflowing of the balls. In other words, the bumps of the chip of Juskey are electrically connected to the electrodes of the chip, whereas the balls of the device (chip) of the present invention are not electrically connected to its electrodes since the balls have not been subjected to a reflowing process and there is flux between the balls and the electrodes. At a later time, the balls are fused at the step of reflowing before or when mounting the device to a substrate, to be thereby formed into bumps electrically connecting the device to the substrate.

Flux is also used in Juskey. However, the flux is for the bonding of the chip to the substrate using the bumps provided on the chip, and is applied to the electrodes of the substrate. In Juskey, the bumps are formed by a conventional bump formation process, such as plating, screen printing, or evaporation, as discussed above.

As such, Juskey does not disclose or suggest the semiconductor device of the present invention.

Greer discloses a semiconductor device having as-deposited solder bumps, and does not describe a device having solder balls only fixed to its electrodes through flux without reflowing.

Therefore, the present invention, as defined in amended independent claims 16 and 17, is not disclosed or suggested by the combination of Juskey, Jr. and Greer. Accordingly, amended independent claims 16 and 17 are patentable.

Boyd and the Periodic Table of the Elements were only cited against dependent claims 3-6. If amended independent claims 16 and 17 are patentable, dependent claims 3-6, dependent thereon, are patentable.

It is therefore submitted that amended independent claims 16 and 17, and claims 3-6 dependent thereon, are patentable.

CONCLUSION

It is submitted that in view of the present amendment and foregoing remarks, the application is now in condition for allowance. It is therefore respectfully requested that the present amendment be entered and the application, as amended, be allowed and passed to issue.

Respectfully submitted,

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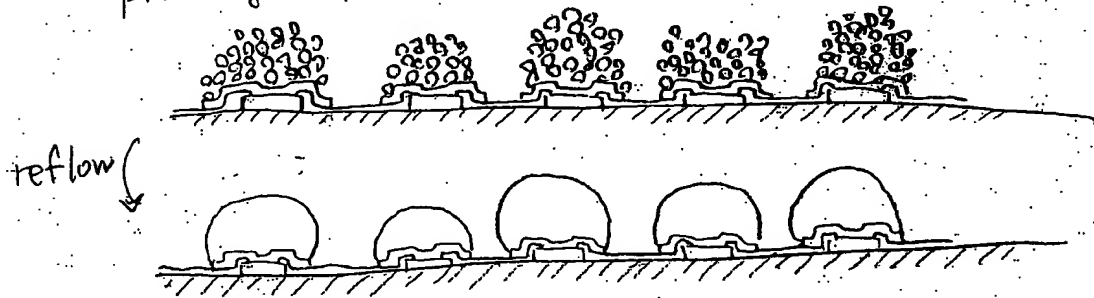
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Appendix I

Screen printing

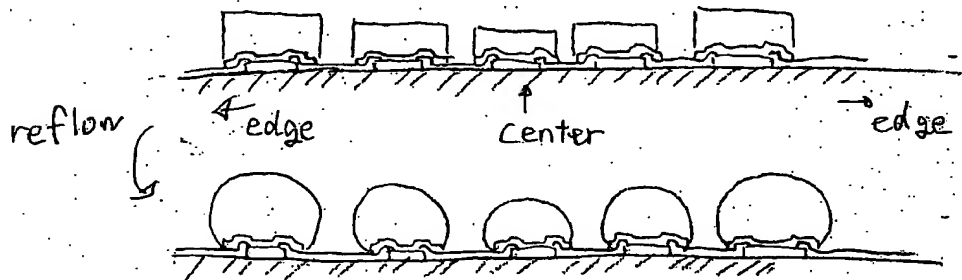
amount Volume has variation.

The amount of paste remaining on electrodes when a mask for printing is removed are varied.



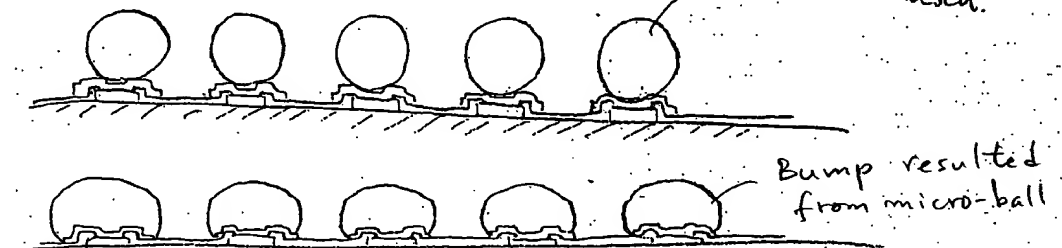
Plating

There is difference in current density during plating at the center and the edge of wafer, and the thicknesses of plated material are varied accordingly.



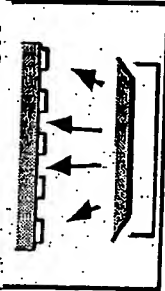

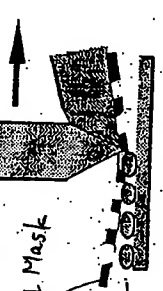
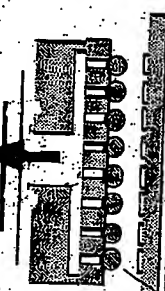
Micro-Ball (this invention)

High accuracy micro-balls are used.



Micro-balls are made with high accuracy, and bumps are not varied.

COMPARISON OF BUMPING TECHNOLOGIES

	ADVANTAGES	DISADVANTAGES
EVAPORATION 	<ul style="list-style-type: none"> • Proven Technology 	<ul style="list-style-type: none"> • Complex process • High material waste • Alloy control difficult • Expensive process
PLATING 	<ul style="list-style-type: none"> • Proven Technology • Fine Pitch 	<ul style="list-style-type: none"> • Several process steps • Alloy control difficult • Environmental issues
SCREEN PRINTING 	<ul style="list-style-type: none"> • High Throughput • Solder paste process 	<ul style="list-style-type: none"> • Not capable of fine pitch • Bump height distribution
MICRO-BALL 	<ul style="list-style-type: none"> • High Throughput • Uniform bump height • Flexible alloy selection 	<ul style="list-style-type: none"> • New Technology

There is a variation in the amount of plated solder between wafer center to edge.

There is a variation in the amount of printed paste.

Balls with high accuracy is used.

Appendix III

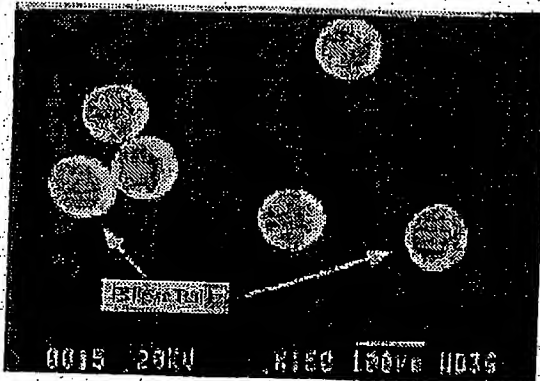


Figure 8. An example of irregular sphericity ball.

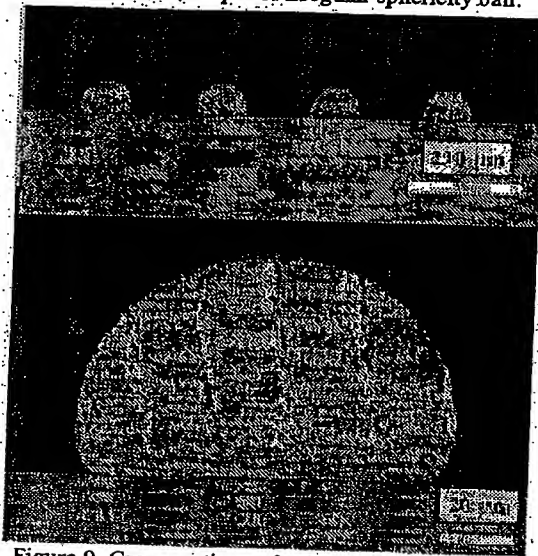


Figure 9. Cross sections of solder bumps formed using solder balls of 100 μm in diameter on Ni / Au UBMs by electroless plating.

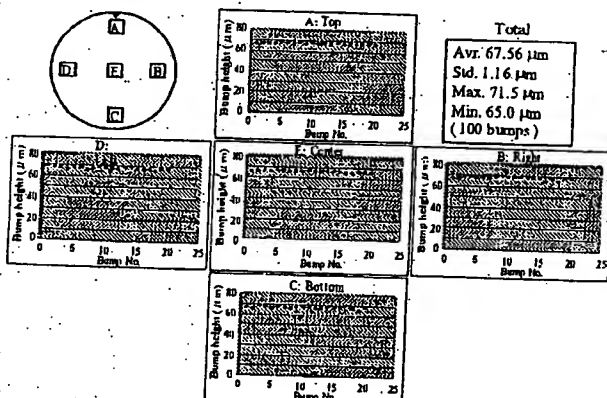


Figure 10. Height variation of micro-ball bumps in an 8 inch wafer.

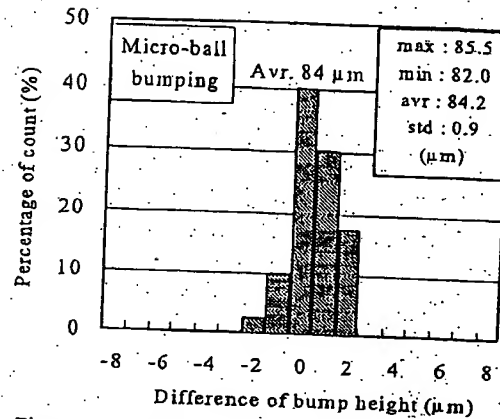


Figure 12a. Height variation of micro-ball bump (bumps formed by micro-ball bumping).

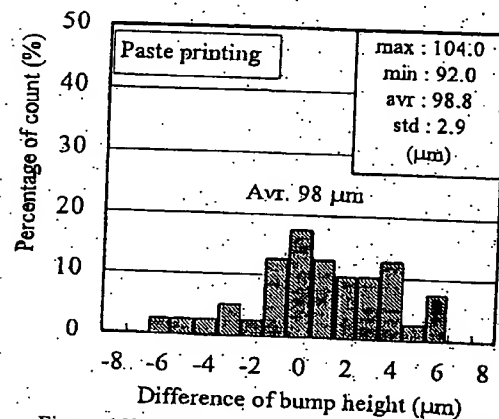


Figure 12b. Height variation of paste printing (bumps formed by printing paste).

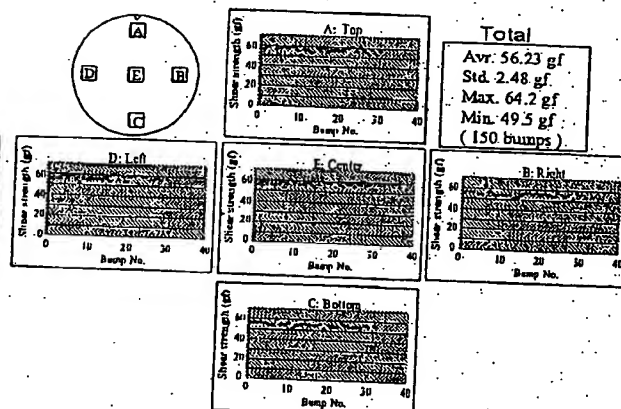


Figure 11. Shear strength variation of micro-ball bumps in an 8 inch wafer.

Micro-Ball Wafer Bumping for Flip Chip Interconnection

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Abstract

A new wafer bumping method using micro-balls was developed that can be used for high-density LSI assembly, specifically for Flip Chip interconnection. Micro solder balls with the diameter ranging from 60 μm to 200 μm were first formed with a high level of accuracy and sphericity. These balls were transferred and bonded to the whole electrode-pads of an 8-inch wafer in one stroke using a fully automated micro ball mounter, which was newly developed. The balls were held on fluxed pads and melted in a reflow furnace. The fluxing was performed using unique stamp system. The productivity and the yield were evaluated under the following conditions. The number of chips on an 8 inch wafer was 616, Pad pitch was 250 μm , Pad number of a chip was 625 (25x25 area array), and the total number of balls on a wafer was 385,000. The yield of forming bumps was confirmed to be higher than 99.995% without repairing and the cycle time of micro ball bumping was ca. 5 min. for an 8 inch wafer. The bump height variation, the bump shear strength and the bond reliability were evaluated in comparison with other methods.

Introduction

The technology of connecting semiconductor chip electrode pads to lead frames with bonding wires finds plenty of field-proven records, attesting to the high level of reliability. This wire bonding technology, therefore, has so far been widely used due to the good bonding quality as well as the flexibility of packaging design. The wiring length, however, sometimes poses a problem as the level of density is further increasing and high-speed devices are required to deliver even greater high-frequency performance. In this situation, part of the chip interconnection technologies using bonding wires is being replaced by the TAB and Flip Chip interconnection technologies of forming bumps on chips and bonding chips via these bumps. Especially FC is the most suitable for the needs.

Since the introduction of the Flip Chip technology by IBM in the 1960s, various Flip Chip bumping technologies have been intensively investigated particularly in the past decade as superior high-density packaging technologies capable of delivering much better electrical performance and a high level of manufacturability than the wire bonding technique [1]-[3]. A typical bumping technology in use today allows the UBM to be first formed in aluminum electrode pads and then solder bumps to be formed in the position of electrode pads on a wafer using shadow masks or photo-resist by means of physical vapor deposition (PVD), such as evaporation and sputtering. Although this vapor deposition process has proven track records with respect of its reliability, a large vacuum

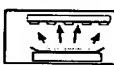

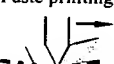

chamber and photo-masks are required and consequently the cost becomes high. In addition, it is pointed out that the majority of vapor-evaporated metals are not used as bumps and eventually become wastes.

Studies in the technology of forming solder bumps using the plating process have progressed to a stage where they can currently achieve commercial viability. Some drawbacks, however, are pointed out: complex process, environment-related problems that must be resolved, and the freedom of alloy plating composition selectivity small. Although the current main alloy composition that is used is Pb-Sn alloy, it is anticipated that the use of Pb is restricted for the reason of environment-related problems, indicating the need to use various types of Pb-free alloy solder.

The method of forming solder bumps by stencil printing or screen-printing the solder paste is recently being made practical. It is understood that this method has the advantage of greater throughput and superior solder material selectivity but is not suitable for the fine pitch bumping operation [3].

This paper describes a new technique for forming Flip Chip bumps on a wafer, featuring the formation of micro-balls with a high level of precision and sphericity. Using this technique, bumps can be formed with high precision and efficiency and, at the same time, much greater flexibility in the selection of bump metals becomes possible. The comparison of each forming method is shown in Table 1.

Table 1. Comparison of bumping methods for Flip Chip.

	Advantage	Disadvantage
Evaporation 	Proven technology	Complex process High material waste Alloy control difficult
Plating 	Proven technology Fine pitch	Many steps Alloy control difficult Environmental
Paste printing 	High throughput Solder paste process	Not fine pitch Bump height distribution
Micro-ball bumping 	High throughput Uniform bump height Flexible alloy selection	New technology Tooling required

Micro-Ball Preparation

Various Pb-Sn alloys, Pb free solder materials and other metals of relatively high melting points can be used as the bump material. The ball material in solid form is cut into units of specified mass that are heated and melted at temperature well higher than the material's melting point and made into balls. The surface tension of liquid metal function to produce balls those make a high level of sphericity. After considering the melting point and oxidation characteristics of the material to be melted, the most appropriate atmosphere, such as, a vacuum atmosphere, a gaseous atmosphere or a reducing atmosphere is selected. The height and pitch of bumps to be formed on electrode pads are considered to determine the size of balls.

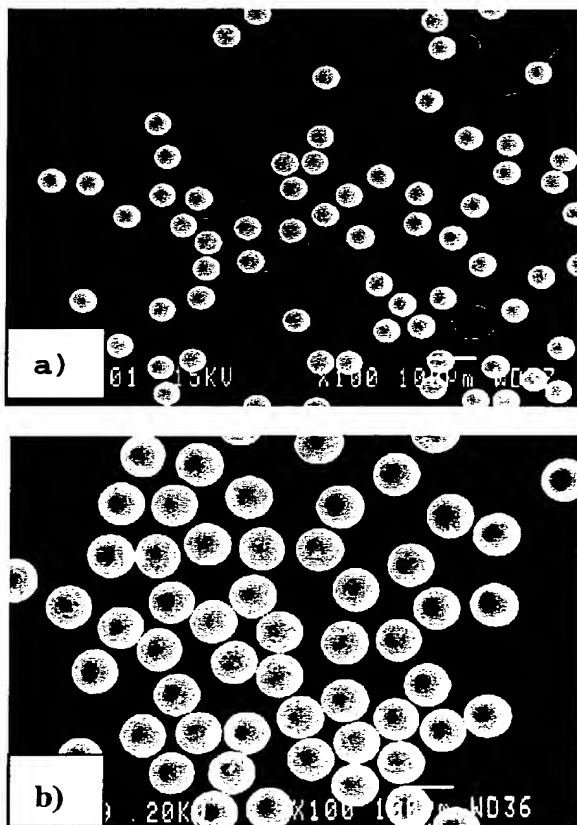


Figure 1. SEM images of micro solder balls. a) 96.5Sn-3.5Ag/ 60 μm in diameter and b) 63Sn-37Pb/ 100 μm in diameter.

Figure 1 shows SEM images of solder balls. In Figure 1-a), Sn-Ag balls of 60 μm in diameter is shown and in Figure 1-b), Sn-Pb balls of 100 μm in diameter is shown. In Figure 2, the size distributions are illustrated. Variations are less than $\pm 3 \mu\text{m}$ and the precision of both the size and sphericity are very high. In Figure 3 the diameters measured on x and y directions of 50 balls (Left: Sn-Ag/ 60 μm , Right: Pb-Sn/ 100 μm) are plotted. The tolerances of both sphericity and size are controlled within $\pm 3 \mu\text{m}$.

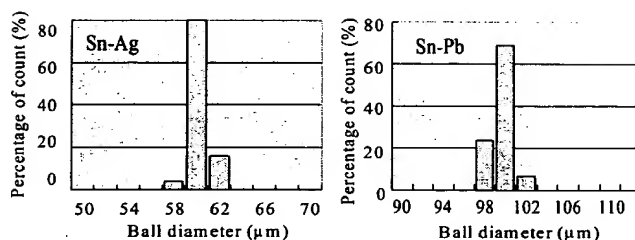


Figure 2a. Ball size distribution for Sn-Ag balls of 60 μm in diameter (left) and Sn-Pb balls 100 μm in diameter (right).

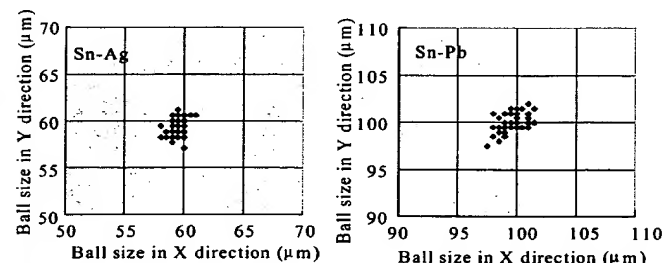


Figure 2b. Diameters measured in x and y directions for Sn-Ag balls of 60 μm in diameter (left) and Sn-Pb balls of 100 μm in diameter (right).

Micro-Ball Arrangement Method

The balls are attached to the locations of the through-holes on one side of the arrangement plate by reducing the pressure in the other side so positioned as to match the points where bumps are to be formed. These balls are transferred to the points where electrode pads are located so that bumps are formed efficiently [6][7].

In Figure 3, the process flow of transferring and forming micro-ball bumps on the electrode pads is shown. For all micro-balls without any excess or shortage to be attached to the through-holes with the arrangement plate and retained in that position, it is necessary to make the micro-balls jump to a certain height by vibrating the ball container and bring the bonding head with the arrangement plate down and closer to the micro-balls. As shown in (1) of Figure 3, the micro-balls are retained in the through-holes (suction holes) by suction. As the diameter of the micro-balls becomes smaller, excess micro-balls tend to adhere to the portion other than the suction holes. Since the micro-ball's own weight is light, a suction leak occurs through an extremely small clearance between a normally attached ball and a suction hole, causing more than one micro-ball to adhere around one suction hole. Contamination and moisture content on the surfaces of the micro-balls also cause excess micro-balls to adhere to the arrangement plate. In order to remove these excess balls and continue retaining normally attached micro-balls in position, ultrasonic vibrations of the most appropriate vibration frequency and amplitude must be applied, as shown in (2) of Figure 3.

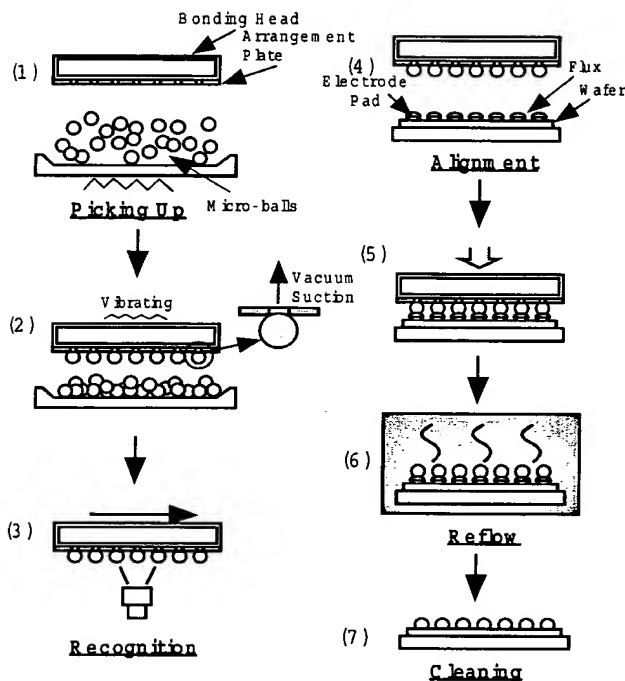


Figure 3. Process flow of micro-ball bumping

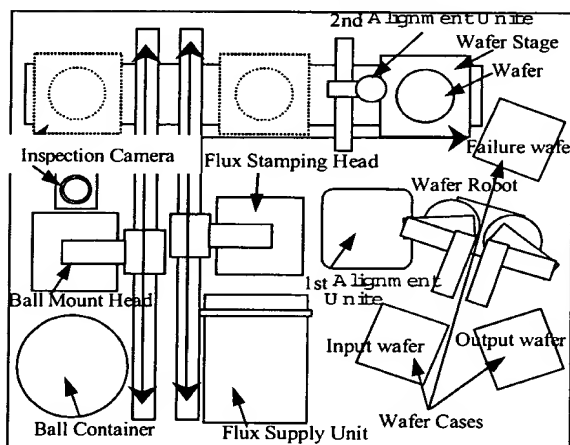


Figure 4. Schematic diagram of the micro-ball mouter.

A piezoelectric vibrator is operated to apply an ultrasonic vibration to the arrangement plate through the bonding head. Figure 5a and 5b show how excess micro-balls adhere to arrangement plate and the effect of the applying ultrasonic (US) vibration. The micro-balls must then be viewed using an imaging processor to verify that the attached micro-balls are correctly arranged on the arrangement plate without any excess or shortage, as shown in (3) of Figure 3. If any of the micro-balls are incorrectly attached, those balls must be removed from the arrangement plate by using vacuuming nozzle. When it is verified by viewing the attached micro-balls that they are properly attached and aligned, the head moves to the bonding stage where the micro-balls are aligned to the

electrode pads on a wafer to which the micro-balls are to be transferred, as shown in (4) of Figure 3. As the last step of this process, the head is brought down and the micro-balls are touched to the electrode pads with a predefined load for transference, as shown in (5) of Figure 3. When the head is brought up, the pressure on the backside of the arrangement plate is increased above the atmospheric pressure to prevent the micro-balls from remaining on the through-holes of the arrangement plate. Before transferring micro-balls, the electrode pads are fluxed by stamping or screen printing. The micro-balls are retained in position of the electrode pads with the function of the adhesion strength of the flux. These temporarily retained micro-balls are heated to the temperature higher than their melting point in a furnace so that they are bonded to UBMs, as shown in (6) of Figure 3.

The authors have developed a unit capable of handling this entire process flow from steps (1) to (5) of Figure 3, fully automatically. Figure 4 shows a schematic diagram of a newly developed system which can be used for the wafer bumping of the size up to 8 inches. Wafers are loaded from a case using wafer robot. After detecting wafer position by alignment units, the wafer is moved to the fluxing stage, where flux is stamped on each electrode pads. The flux stamping plate has elastic bumps for transferring flux to the electrode pads. These elastic bumps are located at the same position as the electrode pads. After flux stamping, the wafer is moved to the ball mounting position. Then the micro-balls are transferred by the method as mentioned above. The machine cycle time is ca. 5 minutes.

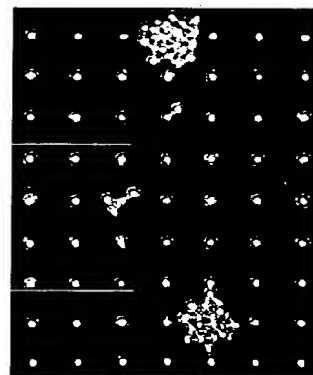


Fig.5a. Without US vibration

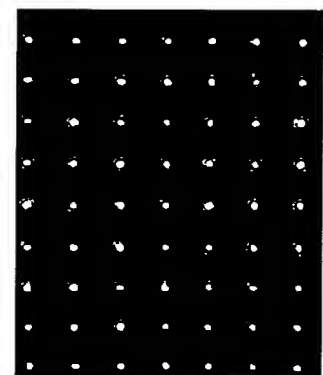


Fig.5b. With US vibration

Figure 5. An example of excess micro-balls adhering to the arrangement plate (5a) and correctly attached (5b). Ball diameter : 100 μm .

Formation of Solder Ball Bumps on the 8 inch wafers

Since the solder has poor wettability with the aluminum electrode pads, it is necessary to form the UBMs. Figure 6 shows a process flow to form solder bumps by transferring solder balls. The UBMs are deposited on the electrode pads on a wafer and the flux is supplied to these electrode pads by stamping. The amount of the flux to be transferred to the wafer could be controlled by squeezed gap of the flux supply unit.

In this experiment, Ni/Au UBMs are deposited by electroless plating. The method of electroless plating has the advantage in cost reduction of UBMs formation compared with the physical vapor deposition. To evaluate the bumps formed by the wafer level bumping system we prepared 8 inch test wafers. On Al electrode pads (size: $100 \times 100 \mu\text{m}$), Ni of $5 \mu\text{m}$ in thickness and Au of $0.05 \mu\text{m}$ in thickness are deposited after zincate pretreatment. Solder balls are then transferred to the UBMs as described in Figure 6. The balls attached to the electrode pads on the wafer are melted and bonded to the electrode pads in a nitrogen atmosphere of reflow furnace, and the flux residue is removed by cleaning. The success rate of transferring the balls to the electrode pads is affected by the grade of ball diameter distribution and, therefore, it is necessary to use the ball with small size variation. An example of the ball with the irregular sphericity leading to transfer error is shown in Figure 8. These ellipse balls may cause choking through-holes of the arrangement plate.

In Figure 7, a picture of an 8 inch wafer with solder bumps and SEM image of solder bumps are shown. There are 619 chips in the wafer and 625 electrode pads per chip (25×25). Total number of pads is 385,000. Eutectic solder balls of $100 \mu\text{m}$ in diameter are used, and electrode pads are set at a pitch of $250 \mu\text{m}$. The balls are positioned on the arrangement plate and transferred to the total pads on the wafer in one stroke. The success rate of ball transferring is obtained to be 99.995% or more. The pad positions of ball missing are repaired by a single ball mount equipment, resulting in the achievement of 100% yield in bumping. In the micro-ball bumping method excess balls can be easily removed before reflow process. In Figure 9, a cross section of these solder bumps is shown. There are no voids observed. The bump height and shear strength are measured, as shown in Figure 10 and 11 respectively. Five different positions are selected for the measurements as indicated in the drawing of the wafer in Fig. 10 and 11. The bump height is $67.6 \pm 3.5 \mu\text{m}$ and the shear strength is $56.23 \pm 7 \text{ gf}$. When a shear test is conducted, fractures occurred only inside the solder bumps. Variation in the height is much smaller, compared with that in other bump formation methods. The Figure 12 shows the comparison of the bump height distribution between micro-ball bumping and screen-printing method. The average value of bump height is $84.2 \mu\text{m}$ for micro-ball bumping and $98.8 \mu\text{m}$ for screen-printing respectively. The difference of the average height is caused by the difference in pad size used and in solder volume. There is significant difference observed in the height distribution. The height variation in micro-ball bumping method is very small.

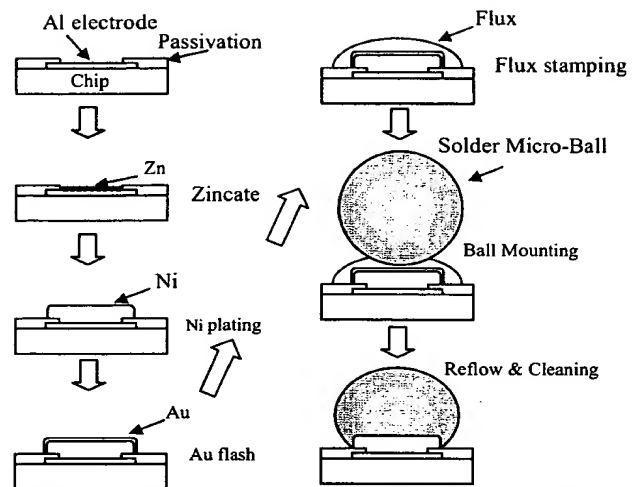


Figure 6. Process flow to form UBMs and solder bumps by micro-ball bumping.

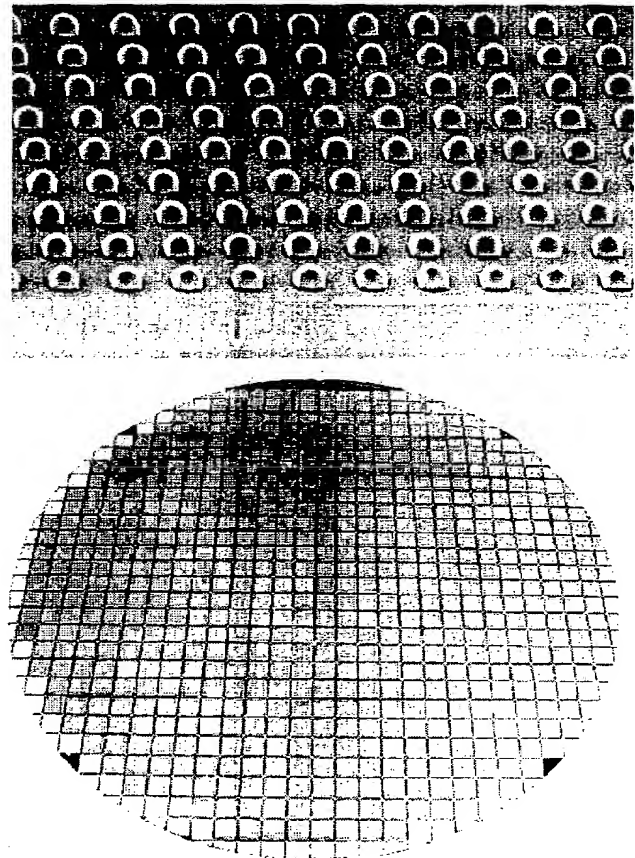


Figure 7. A picture of 8 inch wafer with solder bumps (lower) and SEM image of solder bumps (upper). (63Sn-37Pb solder balls of $100 \mu\text{m}$ in diameter are used. Total number of bumps: 385,000).

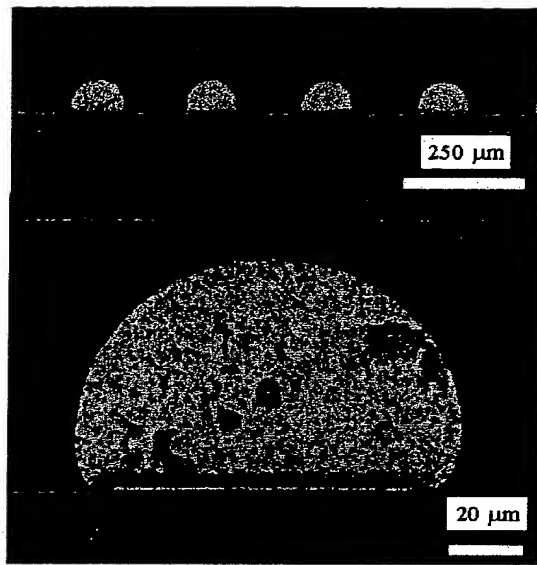


Figure 8. An example of irregular sphericity ball.

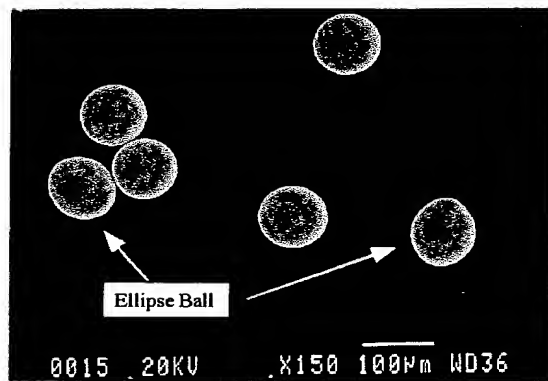


Figure 9. Cross sections of solder bumps formed using solder balls of 100 μm in diameter on Ni / Au UBMs by electroless plating.

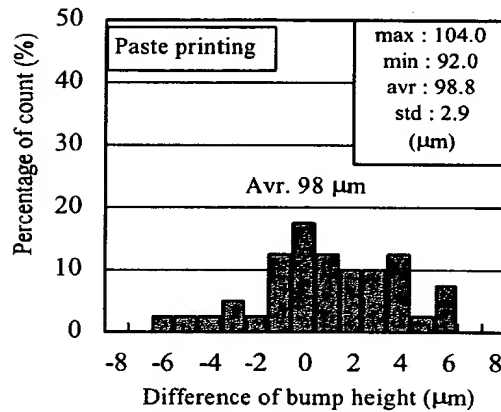
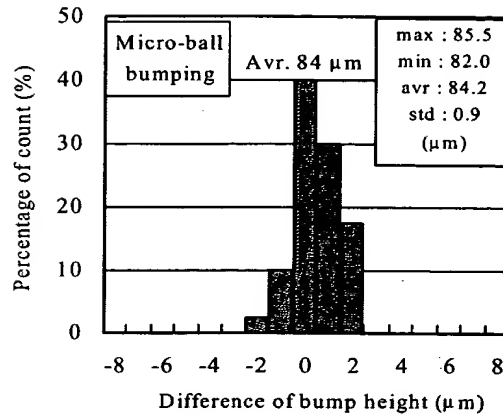


Figure 12b. Height variation of paste printing (bumps formed by printing paste).

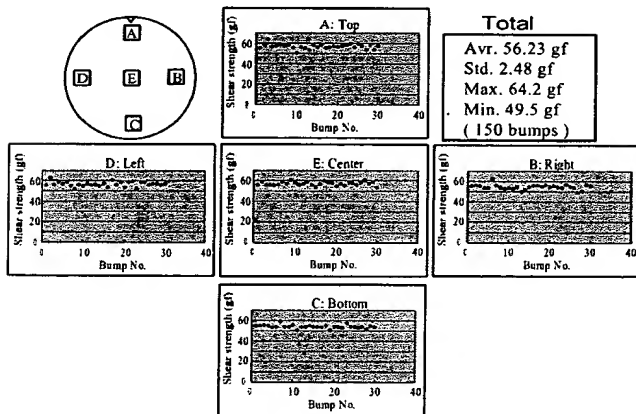


Figure 10. Height variation of micro-ball bumps in an 8 inch wafer.

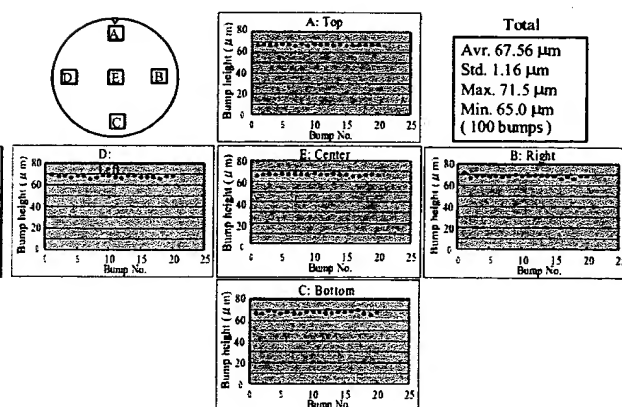


Figure 11. Shear strength variation of micro-ball bumps in an 8 inch wafer.

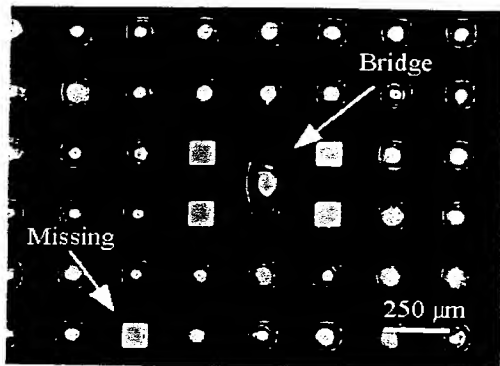


Figure 13. Typical failures of bumps after reflow (solder alloy: 63Sn-37Pb, ball diameter: 100 μm).

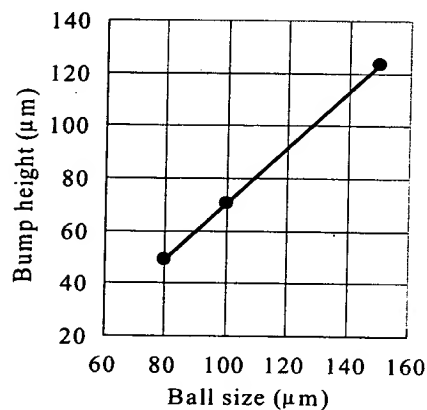


Figure 15. Bump height for the various ball sizes used (80, 100, and 150 μm). Electrode pad size: 110x 110 μm . 63Sn-37Pb solder balls were used.

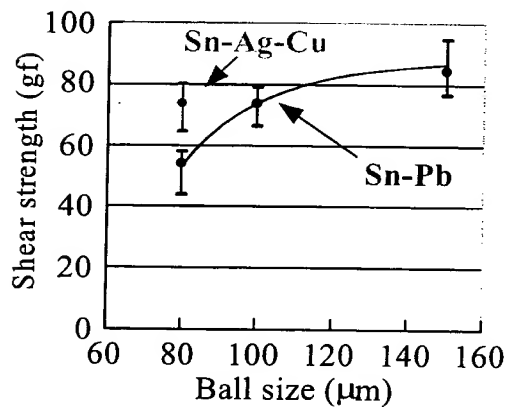


Figure 16. Shear strength of the various ball size (80, 100, and 150 μm). Electrode pad size: 110x 110 μm . 63Sn-37Pb solder balls were used.

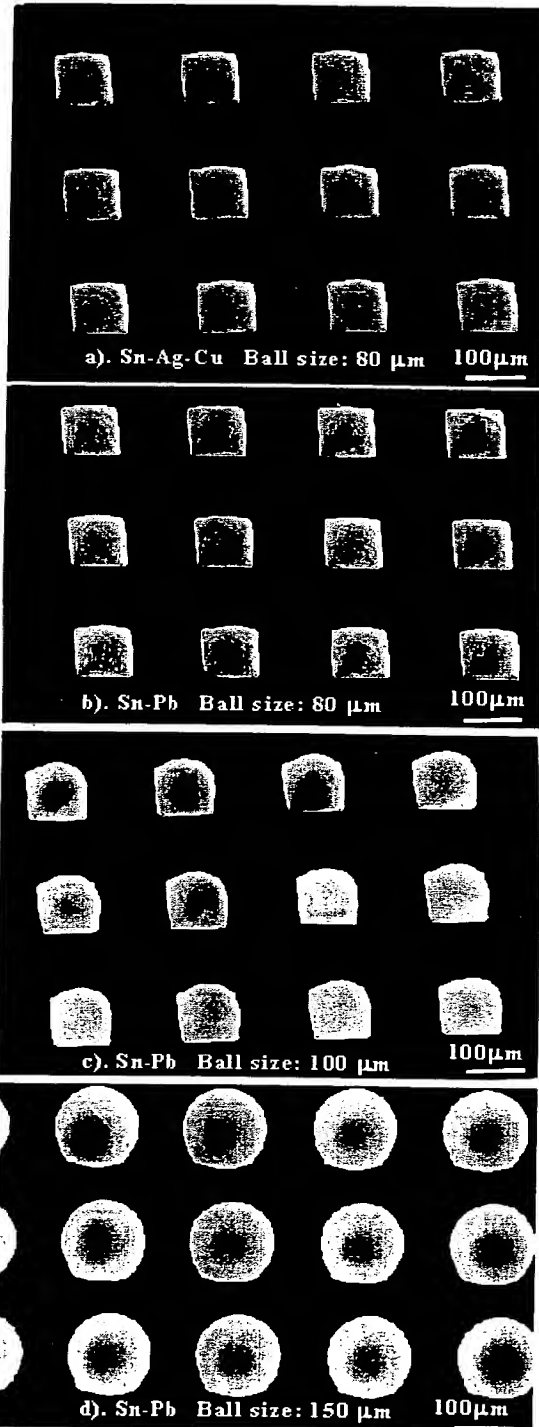


Figure 14. SEM images of bumps formed by using various balls. a) Sn-2.6Ag-0.6Cu/ 80 μm in diameter, b) 63Sn-Pb/ 80 μm in diameter, c) 63Sn-Pb/ 100 μm in diameter, and d) 63Sn-Pb/ 150 μm in diameter (electrode pad pitch: 250 μm).

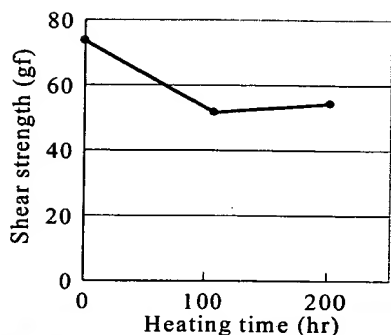


Figure 17a. Shear strength of solder bumps heated at 125°C.

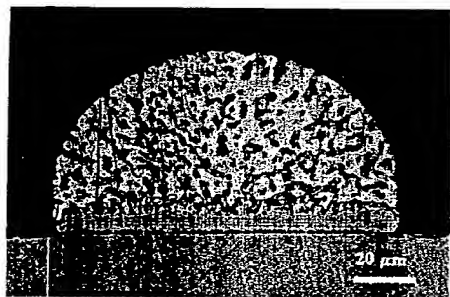


Figure 17b. A cross-section of a micro solder ball bump (heated at 125°C 108 hours).

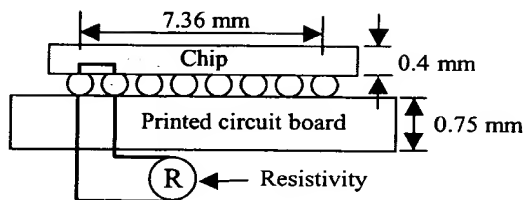


Figure 18a. A schematic diagram of Flip Chip bond for Thermal Cycle Test (Solder ball size: 300 μm).

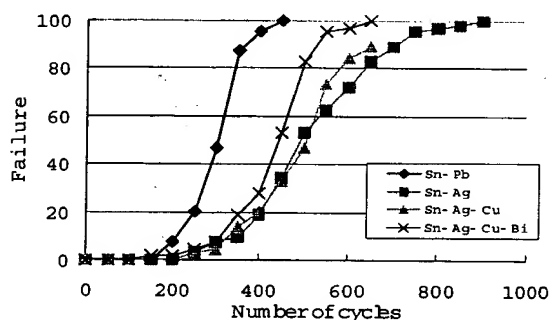


Figure 18b. The result of TCT using 300 μm solder balls (TCT condition: -40°C (20min)/ 125°C (20 min)).

Figure 13 shows typical failure patterns observed after reflow. Such problems as bump-to-bump bridging or ball missing could be resolved by optimizing the thickness and type of flux, or reflow conditions, ball transference conditions.

Figure 14 shows SEM images of bumps formed by using various size of 63Sn-37Pb and Sn-2.6Ag-0.6Cu balls from 80 μm to 150 μm in diameter. For all cases the same size of UBMs (110 μm x 110 μm) is used. The bump height increases with increasing ball size used as shown in Figure 15. There are no significant differences observed in bump shape as well as bump height between Sn-63Pb and Sn-2.6Ag-0.6Cu composition. Figure 16 shows the shear strength of bumps measured as reflowed depending on the ball size. The value of the shear strength for Sn-2.6Ag-0.6Cu alloy is markedly high compared with 63Sn-37Pb alloy. All bumps were sheared inside of the solder bumps.

A test of high temperature heating at 125°C for 200 hours is conducted on the bumps formed by using Sn-Pb balls of 100 μm in diameter. Shear strength of Sn-Pb bumps decreased slightly with heating at 125 °C for 108 hours. The decrease in shear strength is also observed by aging at room temperature after reflow in Sn-Pb bumps. The decrease appears to be related to the precipitation of Pb in Sn base phase. Figure 17b shows an optical micrograph of cross section of the bumps heated at 125°C for 108 hours. The value of the shear strength is kept to be almost constant for further heating.

Furthermore, the junction reliability of the FC bonding in Pb free materials is evaluated by TCT (Thermal Cycle Test). Figure 18a shows schematic diagram of test configuration. In order to clarify the effect of the material, test samples of FC bond are prepared without under-fill where the balls of 300 μm in diameter are used. The solder materials of Sn-3.5Ag, Sn-2.6Ag-0.6Cu, Sn-3Ag-0.75Cu-3Bi and 63Sn-37Pb are tested. A junction state is checked for the bumps of the outermost circumference of chip by resistivity measurement, and the failure number is counted. The samples are thermal cycled from -40°C to 125°C. A result is shown in Figure 18b. All three of Pb free materials are superior in fatigue resistance to 63Sn-37Pb solder.

This paper described wafer bumping method using micro-balls. This micro-ball bump method is also applicable to bumping on diced chips as well as substrate [5]. Figure 19 demonstrates an example of bumps formed on the PCB substrate, having electrode with 140 μm pitch.